between longitude 0° and 60°, as observed by Mr. Denning, may show that the direction of their motion generally follows that of the Sun, and is drawn in towards the Sun.

Mr. Denning says (*Monthly Notices*, vol. 47, p. 39): "Meteors and meteoric radiants display by far the greatest profusion between July and December, and the densest region of radiation lies between 1° and 60° of R.A. This is, indeed, the most active part of the heavens, even as late as November, when it is some 110° distant from the apex of the Earth's way."

The positions of the 918 radiants given in Denning's catalogue (*Monthly Notices*, vol. 50), show about two-thirds grouped in the hemisphere from which the Sun is moving. It must be borne in mind, however, that these observations were chiefly made in the second half of the year.

A diagram at the end of M. Kleiber's treatise on meteor orbits, purporting to give corrected positions for these radiants, shows a more remarkable grouping of meteors behind the Sun's path.

Table VI. shows the apparent positions of the 918 radiants from Denning's catalogue.

Table VII. reproduces M. Kleiber's diagram (see also pp. 258 and 261 of his treatise).

I venture to submit—

1. That the explanation hitherto adopted of the semi-annual variation of meteors is inadequate.

2. That the variation is connected with and mainly due to the cosmical motion of the solar system.

3. That it renders highly probable the cosmical origin and motion of meteors.

1894 *June.*

Motion of Fireballs and Shooting Stars relatively to the Earth.
By W. F. Denning.

That there is a marked distinction in the general direction of motion of fireballs and ordinary shooting stars is a fact which has often impressed itself upon me during the progress of observation. I refer to the frequent tendency of fireballs to indicate radiants which are quite unknown and placed in regions of the sky singularly free from normal showers of shooting stars. In determining the real paths of fireballs from duplicate observations the same feature has been prominently suggested, and has led me incidentally to remark upon it on several occasions. The comparison of a large number of published results with particular regard to the positions of the radiants also bears out this conclusion in a manner not to be mistaken. There is no doubt that the majority

of fireballs move slowly, and that they are travelling in the same direction as the Earth (*i.e.* in direct orbits), for their points of radiation, instead of clustering in the eastern sky, similarly to those of the larger proportion of shooting stars, are placed in the western half of the firmament. Were the orbital distribution of fireballs a promiscuous and perfectly equable one, we should clearly expect that a far greater number of these bodies would meet the Earth than overtake it; but the reverse appears to be the rule from observation, wherefore it becomes obvious that their direction is of a special character.

Whenever an observer is watching for meteors and a large fireball suddenly bursts into view, the great probability is that it will not diverge from a well-defined star shower of the period, but from a westerly radiant which has, perhaps, never been recognised before, and which may only give this single indication of its activity. In proof of the fact alluded to, we have only to recall the paths of many of the finest meteors of recent years. For instance, the brilliant fireball that appeared in the evening twilight of April 22 last was directed from the region of *Perseus* in the north-western sky; the large detonating fireball of January 25 last had a radiant in *Cepheus* in the N.N.W.; the great meteor of 1893 October 1 emanated from near ζ *Draconis* in the N.W.; and many other examples might be readily quoted. In the latter case, though the fireball denoted a radiant in an unusual place, it nevertheless corresponded with the focus of an October meteor shower observed at Bristol in the years 1877 and 1885.

The surprise which has occasionally been expressed at the singular positions of fireball radiants as compared with the known radiants of shooting stars was induced by the assumption that the two classes of objects were identical in their directions. They were certainly not understood to offer a wide distinction in the respect named. But apparently this will have to be admitted, for it is obvious that the radiants of the larger and smaller forms of meteors are not fairly comparable, inasmuch as their distribution is of a special and dissimilar nature. Considering them separately, the radiant centres are in no way curious; indeed, the circumstance of a fireball leisurely streaming across the sky from a westerly direction may be regarded as quite a normal event, though decidedly unusual in the case of an ordinary shooting star.

I recently consulted a large number of fireball observations and radiant-positions * as given in the reports of the Luminous Meteor Committee of the British Association and in various scientific journals, and found that a considerable majority of the descriptions referred to fireballs, which must have overtaken the Earth in her orbit. I omitted the Perseid meteors altogether, as they form a very rich shower, and provide so many brilliant

* Many of these were carefully determined by Professor A. S. Herschel, who also, as secretary of the Meteor Committee, collected and recorded a vast number of useful observations both of fireballs and ordinary shooting stars.

members that their inclusion would have materially and unfairly affected the general result of the inquiry. But the examination was not a thorough one, nor can very exact results be obtained from the data preserved, since in some cases the paths observed have not been recorded with that degree of fidelity and completeness necessary to disclose the precise radiants.

The figures derived from a comparison of 321 of the best observed and largest fireballs which have appeared during the past thirty years are as under :

Large Fireballs.

		Percentage.
Number which met the Earth	131	40·8
Number which overtook the Earth ...	190	59·2

A striking excess is here shown in favour of those travelling in the same direction as the Earth, the numbers being in the proportion of nearly 3 to 2. With regard to shooting stars of the 1st magnitude, the values appear to be essentially different, for I examined a similar number taken at random from trustworthy catalogues, with the following result :

First Magnitude Shooting Stars.

		Percentage.
Number which met the Earth	207	64·5
Number which overtook the Earth ...	114	35·5

In this case there is a large excess on the side of those which met the Earth, as we should naturally expect from theoretical considerations. The difference in the percentages for fireballs and shooting stars is very significant, and apparently demonstrates that, while many of the former travel in direct orbits, the bulk of shooting stars emanate from the eastern region of the firmament, and with the characteristic swiftness of those pursuing retrograde paths.

The perfectly even distribution of meteoric orbits would suggest that a large proportion of meteors generally must fall from radiants in the forward or apex half, while but a relatively small number must diverge from points in the other, or anti-apex, half of the sphere, the calculated proportionate numbers given by Professor Alex. S. Herschel being 85 to 15. Comparing this with the results obtained from large fireballs and 1st magnitude shooting stars, we have the following values :

	Fireballs.	1st mag. Shooting Stars.	Computed No. on even distribution.
Radiants in apex half	40·8	64·5	85
Radiants in anti-apex half ...	59·2	35·5	15

There appear to be four times as many fireballs overtake the Earth as might be expected were their orbits equably arranged, and

without any particular regard to direction of motion. The proportion of fireballs of westerly extraction is so large that the law it suggests must hold good after every circumstance which may have unduly favoured its inception has been allowed for. The 1st magnitude shooting stars exhibit directions more consistent with theory, though the number overtaking the Earth seems to be more than double as many as would be supposed. It is probable, however, that the smaller shooting stars of 4th and 5th magnitudes would still more nearly correspond with the numbers computed on the assumption of a uniform arrangement of parabolic meteor streams. But it must be confessed that evidence is not wanting to show that even the latter are more often dispersed from southerly and westerly directions than would have been thought likely.

Many of the slow-moving and brilliant fireballs alluded to, apart from being distinctly unconformable with the radiants of ordinary meteors, appear to be solitary; but whether this proceeds from the tenuity of their associated streams or from absolute isolation has yet to be ascertained from more extensive observation. I have occasionally made particular efforts to discover whether they were simply fine members of well-defined streams, the radiants of which might be detected by attentive watching. In a few instances this proved to be correct, but in many others not the slightest evidence could be gleaned of any accompanying showers. In each of the latter cases, therefore, the object may either have been single or connected with a meteor group nearly exhausted by the waste of its material during many past ages. Possibly there are groups of large meteors circulating in space without the attendance of the small fragments such as mainly compose our ordinary meteoric displays. It would seem from a comparison of the radiants of doubly observed fireballs that the same position will sometimes offer many repetitions, though the epoch is not always sufficiently near to favour the idea of absolute identity. Thus some splendid fireballs have been projected from the region north of *α Scorpii*, in the summer months, with radiants as follow, as deduced by Professor G. von Niessl, of Brünn:

		α	δ
		°	°
1883 June 3	... ...	250	−20
1883 June 3	... ...	248	−20
1878 June 7	... ...	249	−21
1873 June 17	... ...	249	−20
1879 July 13	... ...	246	−19

Several other large meteors have been directed from the same point in the succeeding months of August and September. There is also a display of similar character having its centre 5° S. of *θ Geminorum*, which is probably quite unconnected with the

Geminids of December 9–12. I have recorded the following meteors from it:

Date.	Hour. h	m	Mag.	Path. From. ° °	To. ° °	Length. °	Notes.
1880 Jan. 2	9	8	> ♃	32 + 60	353 + 56	20	slow, bright train.
1877 Jan. 4	8	51	> ♀	134 + 45	169 + 44	25	slow, $2\frac{1}{2}$ sec.
1886 Jan. 4	11	14	♀	164 + 58	215 + 52	29	slow 3 maxima.
1892 Jan. 11	8	5	♀	21 + 60	318 + 34	48	slow, 7 sec.

The radiant is at $97° + 29°$, and a shower of small meteors apparently precedes it; for in 1886 December 20–29 I determined a radiant at $98° + 31°$ from eleven very slow-moving meteors. (No. 805 in my Catalogue of Radiants, *Monthly Notices*, May 1890, p. 465.)

In the case of radiants which appear to retain similar astronomical positions for several months, it will be found that the finest meteors come from them when they are opposite to the Sun's place, or even westward of that position. Thus there are Taurids in August, September, and October, but the Taurid fireballs come in November. There is a numerous display of meteors from near *α Arietis* during the months of July, August, and September, but it is not until October that it yields really brilliant fireballs. In *Cygnus* there is active radiation from near *κ* in the spring months, but it develops the finest meteors in August, and they are contemporary with the great Perseid display. It is so with a shower in Gemini at $120° + 29°$, visible in the autumnal months, which seems to preserve its fireballs for display in April; and with a November–December radiant at $145° + 7°$ (near *o Leonis*), which supplies its most brilliant members in February and March. In considering these facts, the question arises whether the great difference in velocity has any influence on the brightness of the meteors meeting and those overtaking the Earth. The former are very quickly vaporised and destroyed, and perhaps before the brilliant effects of which they might otherwise be capable are developed. In the case of the slower meteors, the more gradual combustion may possibly be favourable to a more conspicuous aspect. As opposed to this suggestion, however, we must remember that very swift meteors like the Perseids and Leonids sometimes furnish magnificent fireballs, and from this we have to conclude that differences in the velocity of meteors can hardly be supposed to regulate their comparative brightness.

The proportionate numbers of meteor streams meeting and overtaking the Earth are no doubt in some degree affected by the time of night when observations are chiefly made. In the evening the half-sphere including the Earth's anti-apex is spread over most of the firmament, and may be expected to yield a majority of meteors overtaking the Earth. In the morning hours, and especially just before daylight, the half-sphere including the

Earth's apex is predominant, and will certainly supply an abundance of swift meteors meeting the Earth. The fact, therefore, that many of the largest fireballs are observed in the evening hours, when people are often out-of-doors, must certainly influence the numbers in some measure, as the fireballs appearing in the morning hours very frequently escape record, whereas evening fireballs are always seen. I believe, however, that though the circumstances are highly favourable to the detection of such fireballs as appear early in the night, there is undoubtedly a marked preponderance of these bodies then as compared with similar apparitions in the morning hours. If the prevailing conditions could all be smoothed, and perfectly fair averages were obtainable for comparison, there is every indication that the peculiarity here pointed out between the directions of fireballs and shooting stars would be conclusively upheld. The relative proportions given from my partial examination into the subject would no doubt be disturbed, but not so essentially as to controvert the singular fact they appear to affirm so distinctly.

A more complete and searching investigation than I have been enabled to make of the directions of the large fireballs recorded in scientific journals and proceedings of learned societies might readily be undertaken with a view to determine this question with greater certainty, but it would involve considerable labour. The object to be attained would, however, more than compensate for this. I would suggest that in the event of such a discussion being pursued the smaller bolides equal to ♃ and ♀ be excluded, and that only those described as brighter than ♀ be admitted. This would narrow down the work to reasonable limits, and properly confine it to the class of really brilliant fireballs. Meteors of special periodical showers like the Perseids, Leonids, and Andromedes should be rigorously excluded. If such an inquiry could be greatly extended so as to deal also with the smaller bodies it might be instructive to divide meteoric apparitions into four classes, and derive comparative results from each of them.

1. Fireballs of the most brilliant kind.
2. Bolides as bright as *Jupiter* or *Venus*.*
3. Meteors equal to 1st magnitude stars.
4. Shooting stars of the 4th and 5th magnitudes.

The differences found in the general directions of these several classes would, I believe, exhibit a well-marked gradation passing from the direct motion and slow speed of large fireballs to the rapid flights and retrograde orbits of the smallest visible shooting stars.

* Since this was written I have compared a large number of the radiant-positions of the small bolides estimated equal to *Jupiter* or *Venus*, and find that the percentages of their relative directions come nearly intermediate between the figures derived from large fireballs and 1st magnitude shooting stars.

Professor H. A. Newton, in discussing the "Relation of the Orbits of Meteorites to the Earth's Orbit," found that, from 116 observed meteoritic falls, 109 of them must have been following the Earth, while only seven met it. In further summing up his deductions he says that "nearly all the stones in the solar system are moving in direct orbits, very few in parabolic orbits, unless we can assume that stones moving in retrograde orbits for some reason—as, for example, their great relative velocity—may not have been able to pass through the air and to reach the ground in a solid form." He also concludes that the "larger meteorites are allied much more closely with the group of comets of short period than with the comets whose orbits are nearly parabolic" (*American Journal of Science*, 1888 July). This appears to be in agreement with the general directions of ordinary fireballs, which are somewhat rarely heard to detonate, and more rarely still seen to precipitate stones to the ground. But the silent fireballs may not be essentially different either in origin or character from the aerolites which have actually fallen. The observed varieties of appearance may have been introduced by differences in distance, in size, velocity, and condition as affecting their capacity to withstand disruption and dissipation from the heat generated by their violent impact with our atmosphere. Marked differences have been noticed in the composition of meteorites, as everyone knows, and these have led to their classification as Aerolites, Siderites, and Siderolites; but there is also a remarkable diversity in the character of certain terrestrial stones. The opinion has thus been gaining ground in late years that we may take the whole of meteoric objects as displaying a community of origin, the apparent departures from uniformity being due to the vicissitudes these bodies have to encounter in planetary space, to the variable conditions under which they individually become visible, and to the destructive reception they instantly meet with on rushing into the air.

Bristol:
1894 *June* 6.

The Discovery of Comets. By W. F. Denning.

Observers before devoting themselves to any particular line of work naturally consider the prospects offered and the amount of labour likely to be expended in ensuring reasonable success. Comet-seeking is generally regarded with dubious feelings, for though the observer may be attracted by the chance of effecting a discovery, he nevertheless hesitates before entering upon a research essentially requiring patience and perseverance in an